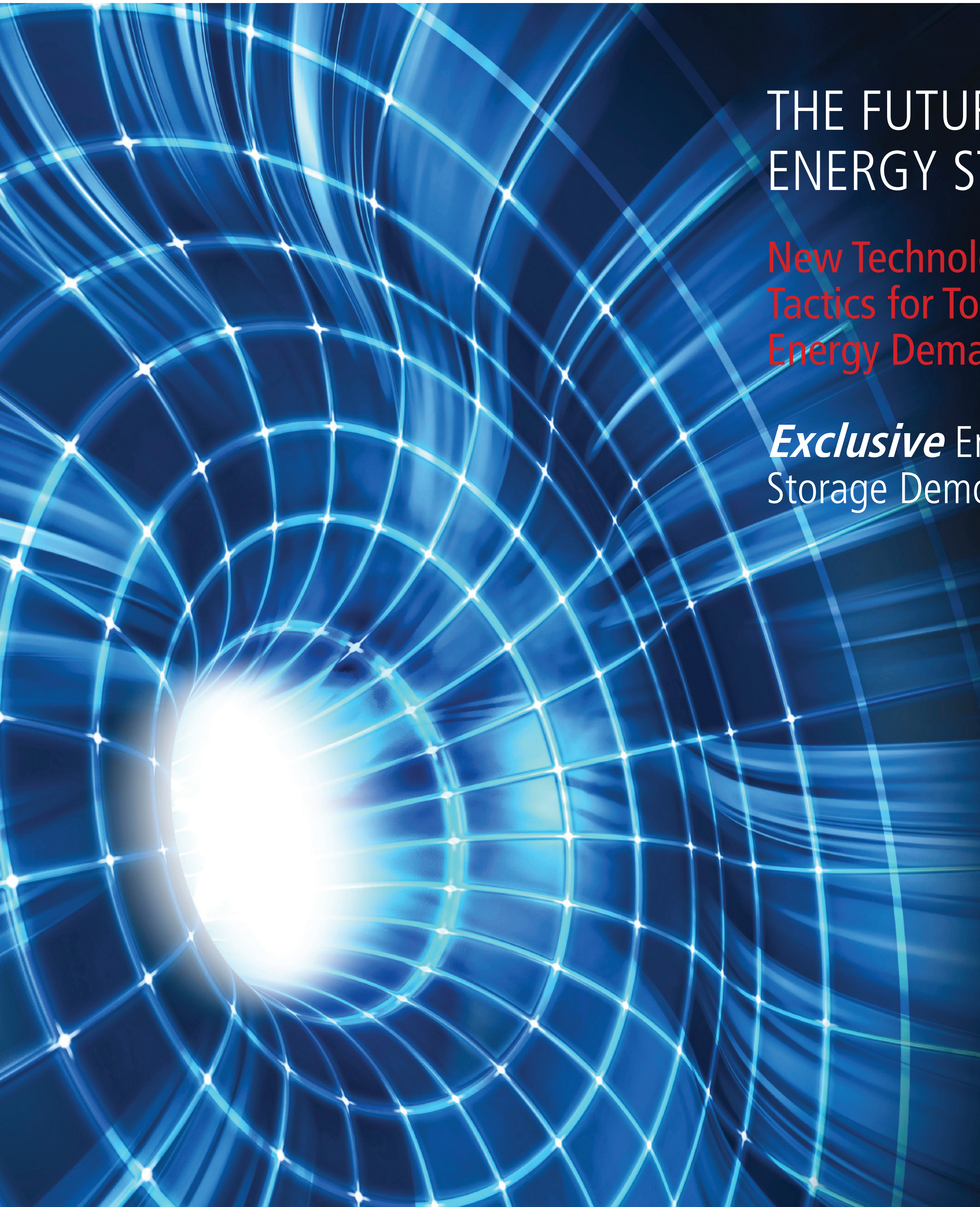
EESDP 13

Electrical Energy Storage Demonstration Projects

Sand Number: 2013-8638P



THE FUTURE OF ENERGY STORAGE

New Technology and Tactics for Tomorrow's Energy Demands

Exclusive Energy Storage Demonstrations

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About EESDP Journal

The EESDP Journal is a collection of technical reports of the current areas being explored by DOE National Laboratory scientists and technicians involved in the research and development and deployment (R&D and D) of electrical energy storage materials, devices, equipment, and facilities through purposed demonstration projects.

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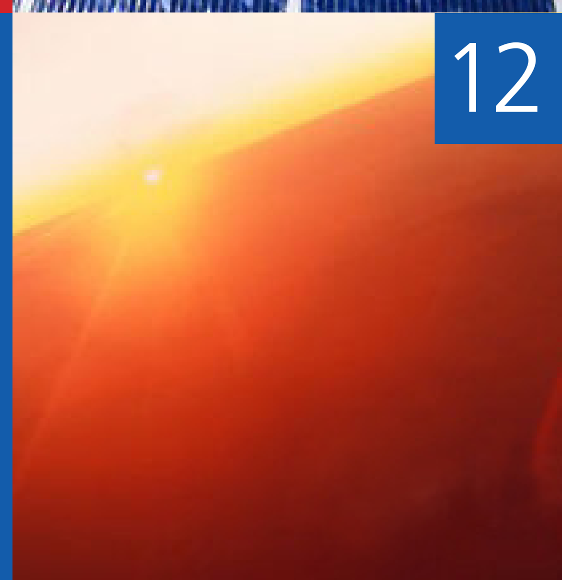

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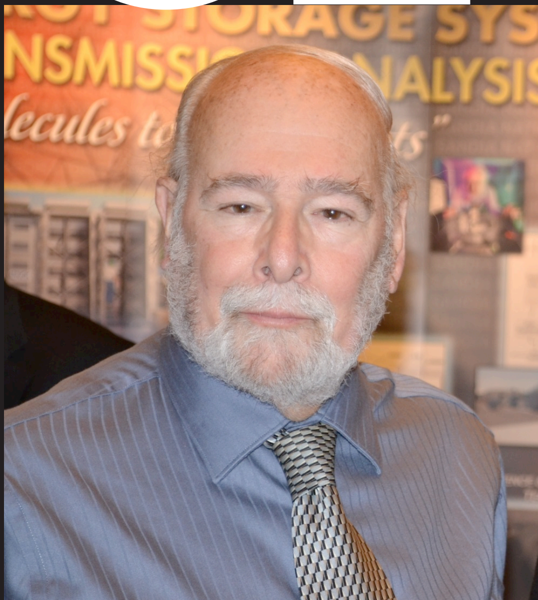


Dr. Imre Gyuk
Energy Storage Program Manager,
Office of Electricity Delivery and Energy Reliability

The U.S. Department of Energy (DOE) and Sandia National Laboratories are pleased to share this limited edition Electrical Energy Storage Demonstration Program Journal.

During the past four years, progress in the application of electrical energy storage has accelerated considerably. Some of the advances include that a Federal tax incentive proposal has been introduced in Congress, California has passed a storage-related mandate, and the Federal Energy Regulatory Commission has fielded a Notice of Proposed Rule Making and then an Order (755) specific to energy storage pay-for-performance market incentive. Various Independent System Operators (ISOs) are already developing appropriate signals, tariffs, and market structures. Extensive storage deployment has occurred in Hawaii to help balance the extensive introduction of renewable generation. Multi-million dollar rate cases are being submitted to public utility commissions. Japan has announced an incentive program for residential storage and China has ambitious plans for deploying storage and smart-grid technology.

"At the beginning energy storage was a virtually unknown concept. But over the years, to a not inconsiderable degree due to our efforts, storage has become one of the most exciting topics in the electricity field."

elivery/Reliability

Resilience

New storage technologies are being proposed and developed such as the new lead-carbon batteries, innovative flow batteries and improved lithium-ion batteries. The investment community is beginning to show considerable interest in these technologies. The newly created ARPA-E has offered a venue for support of potentially transformational new technologies. The DOE's Office of Basic Energy Sciences has created six new Frontier Energy Research Centers focusing on fundamental research on energy storage, and the Office of Electricity Energy Storage program has experienced a substantial funding increase for its diversified program. It is also noteworthy that there are several large loan guarantees for storage projects issued by the DOE, including two 20-MW frequency regulation facilities.

The American Recovery and Reinvestment Act (ARRA) of 2009 provided sizable support for 16 selected projects funded with $185 million and a $585 million cost share. Current projects range from compressed air and grid-scale battery systems for wind support to frequency regulation and distributed storage. The first of the ARRA projects, an integrated photovoltaic and storage using lead-carbon technology, was commissioned in September 2011. During the next years, the program will seek the completion of many more projects that have been completed in previous storage facilities.

International developments, such as the creation of a new energy research institute focusing on storage in the Basque country, increasing interest in the European Community, and ambitious storage deployment in the countries of the Arab Gulf are also significant.

This journal addresses a wide range of energy storage technologies. Each technology is contributing to the goal towards achieving the Office of Energy's core mission of electric grid modernization for a flexible, reliable, resilient electricity delivery system. The Energy Storage Demonstration Program aids in accomplishing this mission through meaningful research and development of new materials, system application of power electronic conversion devices that connect resources to the grid, and formation of academic, industrial, commercial and military partnerships as well as collaborations with state energy offices who require emergency preparations to shore up local and regional power grids.

While some may criticize the "all of the above" strategy that has been employed in energy storage research, applications, and implementation, this approach is necessary to develop the energy storage industry. Electric energy storage has slowly become one of the most exciting topics in the electricity field. The next major step is the development of major markets. This may take regulatory actions based on data from existing deployments. If we are moving aggressively toward the smart grid, then it is energy storage that will get us to that goal.

Dr. Gyuk leading discussion with international energy storage professsionals.

Organizations: Mission Statement

Department of Energy

The United States Department of Energy (DOE) is a Cabinet-level department of the United States government that was formed in 1977. The mission is to ensure America's security and prosperity by addressing its energy, environmental, and nuclear challenges through transformative science and technology solutions; catalyze the transformation of the nation's energy system and secure U.S. leadership in clean energy technologies; maintain a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity; and enhance nuclear security through defense, nonproliferation, and environmental efforts.

Office of Energy

The Office of Electricity Delivery and Energy Reliability (OE) is a program office within DOE that works with the United States Department of Homeland Security and other agencies to enhance the security of the nation's critical energy infrastructure. The mission of OE is to lead national efforts to modernize the electric grid; enhance security and reliability of the energy infrastructure; and facilitate recovery from disruptions to energy supply. OE accomplishes this mission through research, partnerships, facilitation, modeling and analytics, and emergency preparedness.

Sandia National Laboratories

Established in1948, the Sandia National Laboratories are two major United States Department of Energy research and development national laboratories located in Albuquerque, NM and Livermore, CA. Sandia enhances the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems and provides the most effective and efficient technologies and enterprise-level solutions to the nation's highest-priority risks associated with weapons of mass destruction and catastrophic incidents.

It is Sandia's mission to maintain the reliability and surety of nuclear weapon systems, conduct research and development in arms control and nonproliferation technologies, and investigate methods for the disposal of the United States' nuclear weapons program's hazardous waste. Sandia is also invested in research and development in energy and environmental programs, as well as the surety of critical national infrastructures.

Pacific Northwest National Laboratory

Pacific Northwest National Laboratory (PNNL), founded in 1965, is another US DOE National Laboratory. PNNL scientists conduct research and development to strengthen US scientific foundations for fundamental research and innovation; prevent and counter acts of terrorism through applied research in information analysis, cyber security, and the nonproliferation of weapons of mass destruction; increase the US energy capacity and reduce dependence on imported oil; and reduce the effects of human activity on the environment. Researchers at PNNL's Radiochemical Processing Laboratory are developing processes to advance the cleanup of radiological and hazardous wastes, the processing and disposal of nuclear fuels; and the production and delivery of medical isotopes.

Oak Ridge National Laboratory

Oak Ridge National Laboratory (ORNL) is a multi-program science and technology laboratory located in Oak Ridge, Tennessee with 4,400 staff and an additional 3000 guest researchers per year. In 1943, ORNL was founded with the sole purpose to carry out the pilot-scale production and separation of plutonium for the World War II Manhattan Project. ORNL's scientific programs focus on materials, neutron science, energy, high-performance computing, systems biology and national security.

ORNL's mission today is to deliver scientific discoveries and technical breakthroughs that will accelerate the development and deployment of solutions in clean energy and global security. ORNL also performs other work for the Department of Energy, including isotope production, information management, and technical program management, and provides research and technical assistance to other organizations.

Synergy of Mission

Dr. Sean J. Hearne

Cohesive Goals & Actions

Sandia National Laboratories' (SNL) Energy Storage Systems Program is focused on accelerating the adoption of energy storage solutions for a reliable, resilient grid that will ensure America's energy security. This mission requires innovative solutions that address key challenges in materials, systems, and deployment. Much of the program's success has resulted from extensive collaborations with industry, municipal and state governments, universities, and the two other OE funded partner laboratories – Pacific Northwestern National Laboratory (PNNL) and Oak Ridge National Laboratory.

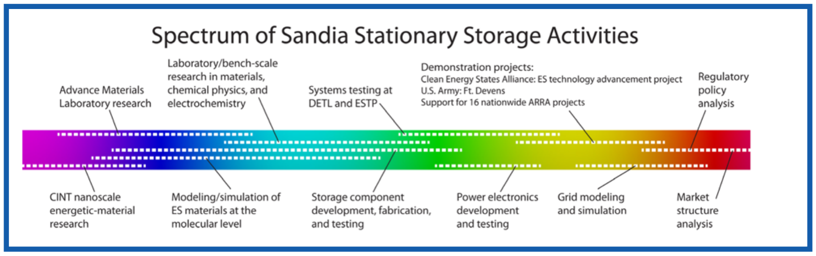
SNL's Energy Storage Systems Program is structured to systematically address challenges by targeting four key areas: materials development, power electronics, grid analytics, and demonstrations and testing. The materials development projects provide revolutionary improvements to energy storage systems including batteries, capacitors and flywheels to improve the performance, reliability and safety of these systems. Advances in power electronics are needed to meet the demanding challenge of energy loss during shifting of energy to and from the grid into storage devices. To address this need, SNL has targeted research into the development of wide-band gap semiconductor materials that allow for higher voltage operation and subsequently lower parasitic losses. Over the past ten years, SNL's well recognized work in power electronics has received four R&D 100 Awards with more than 40 publications.

A major concern of utilities and power regulators is how and where to implement energy storage to ensure the maximum return on investment. SNL's grid analytics projects use validated models to provide guidance for the deployment of energy storage to enable decision makers to make the informed choices about which size, location and best market applications will provide the most benefit. As an example, SNL's modeling and analysis storage study of the public utility NV Energy, in collaboration with PNNL, evaluated the economic viability of grid-level storage for the utility's service area in 2020 and demonstrated that, with appropriate valuation, grid energy storage could provide significant financial advantages. SNL further enables energy providers and consumers to make informed decisions concerning energy storage systems through its provision of the Energy Storage Projects Database[1] and the DOE/EPRI Energy Storage Handbook.[2]

The Energy Storage Systems Program at SNL is actively working towards a more reliable, resilient grid for the American people. Through the integration of diverse capabilities, Sandia's projects have assisted US regulators, industry and, in turn, consumers in meeting the challenges of grid-scale energy storage. SNL's efforts to research, develop, test, assess, and implement energy storage solutions are working to facilitate the goal of the DOE and OE, "to enhance the security of the nation's critical energy infrastructure."

Dr. Sean J. Hearne
Manager, Sandia National Labs' Energy Storage Technology & Systems Department

[1] http://www.energystorageexchange.org/
[2] http://www.sandia.gov/ess/publications/SAND2013-5131.pdf



Spectrum of Sandia Stationary Storage Activities

SNL Energy Storage

Daniel Borneo

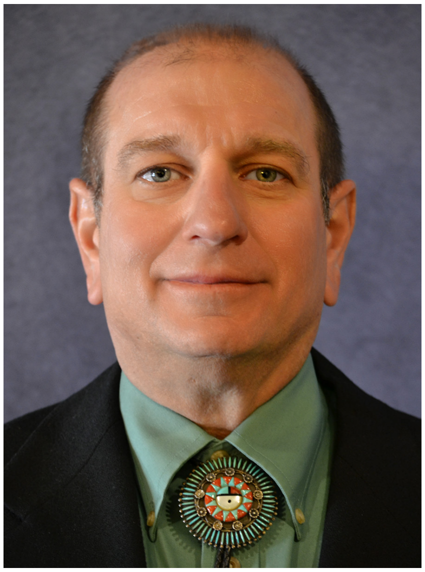
My name is Dan Borneo. I am a vegetable farmer who happens to also be an electrical engineer. I am thankful to Dr. Imre Gyuk of the Department of Energy's Office of Electricity Delivery and Reliability for entrusting the administration of the Energy Storage Demonstration Program to me.

Typically, I approach the challenges of the Storage Demonstration Program by starting with the end goal in mind. The rudimentary function of my group at Sandia National Laboratories (SNL) is to support demonstration projects for major utility-scale energy storage installations.

The purpose of our work is to verify technical performance, validate system reliability, and establish costs and benefits of electrical energy storage systems that can be replicated and adapted to electric utilities throughout the various regions of the United States. The energy storage systems depend on the specific facility and the specific applications that include emerging and existing technologies for advanced batteries, ultra capacitors, flywheels, etc. The application areas of interest are equally varied and may include but are not restricted by renewable energy resources like solar and wind energy technologies, transmission and distribution upgrade deferrals, and system regulation through ancillary services provided to the electric power grid.

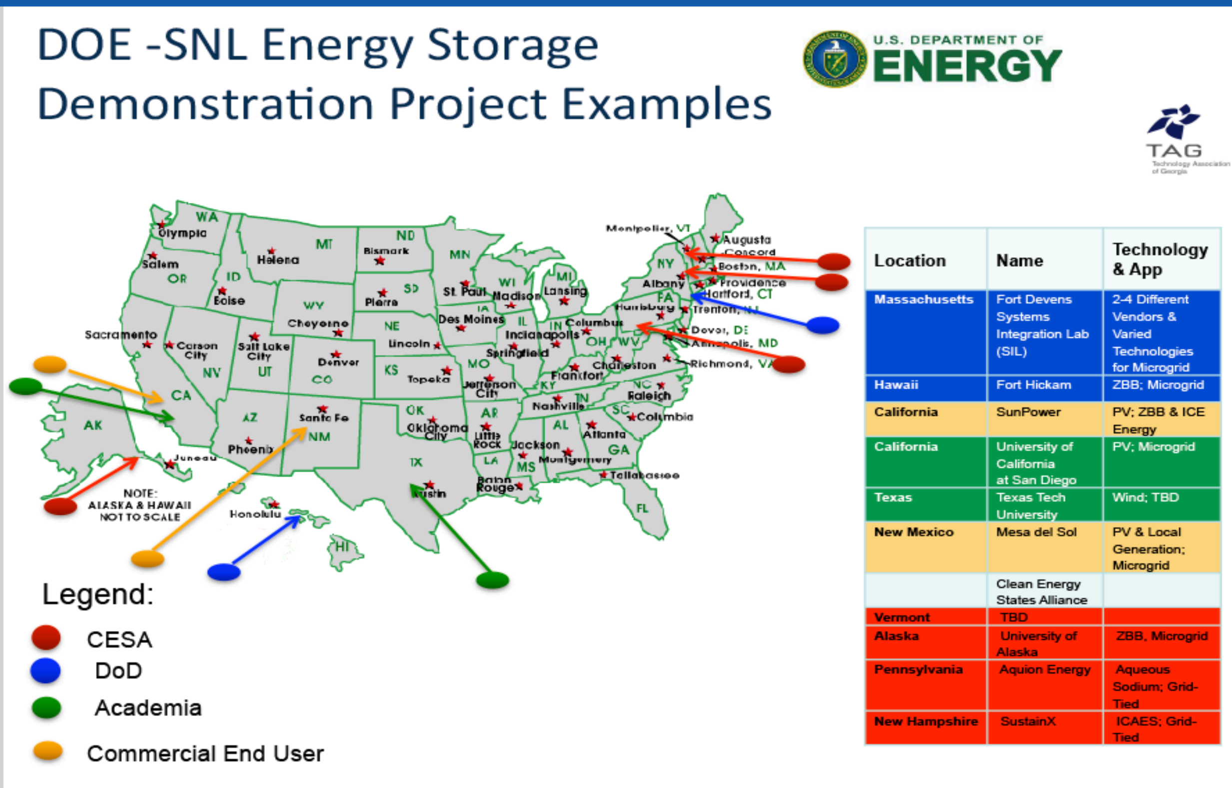
Each demonstration project attempts to tackle one or more of the following goals:

- Use of energy storage to improve the feasibility of microgrids (islanding)
- Incorporation of energy storage as support for a self-healing grid
- Improvement of emergency response infrastructure with energy storage devices or equipment
- Integration of renewable energy penetration at the source or anywhere on the grid regardless of the variable nature of solar and wind resources
- Enhancement of the reliability and resilience of the grid by using energy storage to provide ancillary services
- Advancement of power conversion systems for a more efficient and cost-effective solution for grid function improvement
- Improvement of electricity transmission and distribution by using energy storage to enhance power quality.



"The rudimentary function of my group at Sandia National Laboratories (SNL) is to support demonstration projects for major utility-scale energy storage installations."

ge Demonstration Program



This map displays the footprint of SNL Electrical Energy Storage demonstration projects.

Location	Name	Technology	Environment/Application
Massachusetts	Fort Devens	2-4 Vendors and Varied Technology/Military Nanogrid	Forward Operating Base
Hawaii	Fort Hickam	Zinc Bromide Military Microgrid	Military Base
California	SunPower/Total	ZBr & ICE Energy/ Renewable PV	Commercial Applications
California	Univ. of Calif. at San Diego	Microgrid,PHEV Renewable/PV	University Campus
Texas	Texas Tech Univ.	Wind Energy	University and Industry Testbed
New Mexico	Mesa Del Sol	Lead Acid-GS, EP, Fuel Cell/ Microgrid with local generation; PV	Commercial and Industrial
Varied	Clean Energy States Alliance (CESA)	**TBD**	**TBD**
Alaska	ZBB	Zinc Bromide Microgrid	University (Research & Development
Pennsylvania	Aquion Energy	Aqueous Sodium; Grid-Tied	Industrial Manufacturing Facility
New Hampshire	SustainX	ICAES; Grid-Tied	Industrial Manufacturing
In negotiation	Enervault	Iron Chromium	TBD/based on state selected

Summary Snapshot of Electric Energy Storage Demonstration Projects managed by SNL.

SNL Energy Storag

Daniel Borneo

SUMMARY

If we acknowledge that the goal of the Electric Energy Storage Demonstration Program is to encourage investment in critical services that impact the next generation grid, then the list of commercial stakeholders would suggest that we are properly positioned to achieve our objective. We develop proper test platforms, collect meaningful data, and work with analysts, engineers, and commercial investors in different environments throughout the country to understand how best to satisfy requirements related to bringing emerging technologies and their applications to a robust market.

Our approach is based on the challenge to use energy storage components, equipment, and facilities. Regarding next steps, - we have done an excellent job of pushing the transformational architecture available in electrochemical

research and development; we are fully engaged in power electronics for grid applications, however we need the next push for the controls mechanisms and technicians to create a viable market for such diverse applications and technologies available in the area of electric energy storage.

Commercial Stakeholders in Grid Energy Storage

SUPPLIERS

- Storage Manufacturers*
  - Aqueous Sodium (1)
  - CAES (14)
  - Sitable CAES (1)
  - Electro-chemical Capacitors
  - Flow (7+3)
  - Flywheel (16)
  - Li-ion (14)
  - Lead Acid (>8)
  - Metal-Air (9+2)
  - Pumped Hydro (2)
  - Sodium Sulfur (1)
  - Solid State (1)
- Power Electronics
  - Inverters
  - Controllers
- OTHER
  - Electrical Equipment Manufacturers
  - Integrators
  - Designers

CLIENTS

- Developers
  - Renewables
  - Community/City
- Utilities
  - Distribution
  - Transmission
  - Generation
- End Users
  - Commercial
  - Industrial
  - First Responders
  - Microgrids
  - Residential
  - Military
    - Forward Operating Bases
    - Military Base Microgrids

U.S. DEPARTMENT OF ENERGY

Sandia National Laboratories

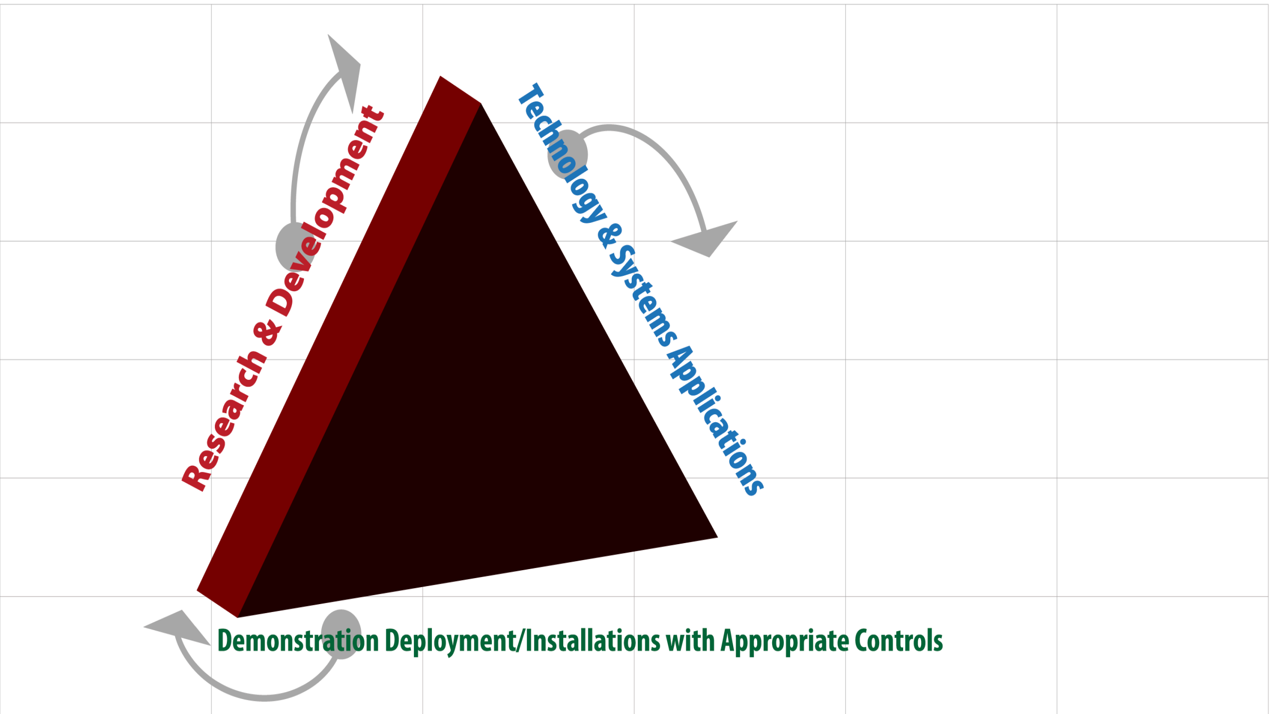
e Demonstration

Program

The illustration below captures the triad concepts

The Ideal Future of ESS

Principles of the SNL **Energy Storage Demonstration** Program



The ideal next step for the Electrical Energy Storage Demonstration Projects to successfully achieve needed reliability and resilience is a triad that includes:

- Research and Development
- Technology & Systems Applications
- Demonstration Deployment/Installations with Appropriate Controls

This triad requires balancing energy policy mandated and implemented by federal, regional, state, and local regulatory entities.

Please note, this journal includes a directory of the current energy storage demonstration projects managed by Sandia National Laboratories.

Discussion

D. Rose & S. Ferreira

Performance Testing of Zinc-Bromide Flow Batteries for Remote Telecom Sites

Telecommunication (telecom) sites are typically located far from the (AC) electric grid. Electrical energy storage options can satisfy the technical challenges associated with providing reliability, longevity, and cost-effectiveness for certain telecom systems. Zinc Bromine (Zn-Br) flow batteries can support unique infrastructure advantages to remote telecom applications.

Telecommunication facilities, building backup power systems and personal electronics use various battery technologies representing a range of standard electrical energy storage applications. Batteries allow these systems to function for a period of time without the necessity of generating electricity. The recharging of batteries is easily achieved when an electric system is connected to the electric grid.

At remote telecom sites, a power line can prove to be prohibitively costly or timely to build due to environmental, engineering, licensure and maintenance considerations. Batteries offer advantages for remote locales; however there are tradeoffs:

- Systems require either an installed diesel generator or distributed renewable energy resources to provide reliable power with longevity for the telecommunications equipment.
- Based on cost, peak load, and over-engineering, the conventional Commercial Off-the-Shelf (COTS) generator has a greater power output than the average telecom load requires. A system characterized by a smaller generator load, however, presents an opportunity to run the entire system efficiently and save fuel.

Zinc-Bromide batteries have several unique characteristics that set them apart from other chemistries:

- Zinc-Bromide is a normally empty system; it is fully discharged during storage and shipment and hence has zero DC voltage on its terminals.
- Charging it puts voltage on the DC bus which it will hold until discharged again.
- Just as lead-acid batteries need to be fully charged on a regular basis to maintain life, zinc-bromide batteries must be fully discharged every few days to maintain life.

A ZN-BR battery saves fuel based on the runtime and efficiency of the generator. The generator runs at a higher set point, charging the battery and supporting the load, then it turns off and lets the battery support the load until it runs out of energy. Repeating this duty cycle would allow an installed generator to run at a higher power for a shorter duration, making it run more efficiently and avoid wet stacking.

The ideal fuel savings can be calculated given the generator fuel curve and duty cycle. The Duty Cycle (DC) of the generator can be calculated using the Equation 1:

$$DC=\frac{1}{1+\frac{\text{Efficiency} \times \text{Charge Rate}}{\text{Discharge Rate}}}$$

Equation 1

Where:

- Efficiency is the electrical energy efficiency of an energy storage device
- Charge Rate is the Maximum charge rate of the energy storage or the difference between generator rating and telecom load (whichever is less)
- Discharge Rate is the total DC telecom load.

If the maximum discharge rate of the energy storage device is not sufficient to support the load, then the duty cycle is set equal to unity because the generator will be able to turn off.

The Fuel Savings (FS) for the using cycle can be calculated in % gpm using Equation 2:

$$FS(\%gph)=\frac{F_1-F_2 \times DC}{F_1} \times 100\%$$

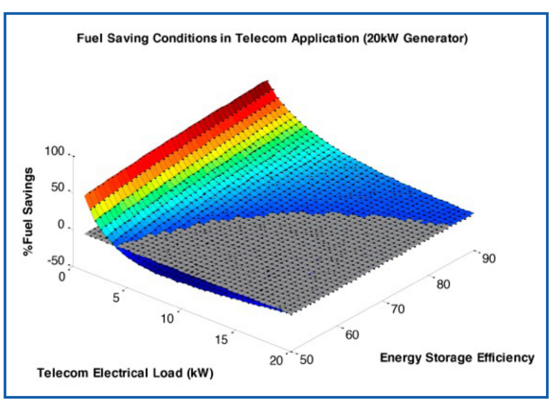
Equation 2

Where:

- F1 is the fuel consumption rate of the generator only supporting the load
- F2 is the fuel consumption rate of the generator supporting the load and charging the battery

Figure1 shows a plot of the percentage fuel savings using this calculation over a range of energy storage efficiencies and telecom electrical load. In cases of low electrical load compared to generator size there is a significant gap to exploit for fuel savings. Additionally, the more efficient the energy storage device is, the better the fuel saving performance of the system. The gray plane shows the zero fuel savings decision boundary. Below this line the implementation of energy storage will actually cause higher fuel usage.

Figure 1 Fuel Savings Decision Boundary



There can be a significant margin for fuel savings at remote telecom sites. Figure1 shows the potential for energy storage to save fuel over a range of electrical load and storage efficiency. Low electrical load compared to generator rating and highly efficient storage of electrical energy can be utilized to a significant benefit. Zinc-bromide flow batteries are one such technology that can be implemented to exploit this margin. Its high energy density, wide operational range, and round-trip efficiency make it applicable in many remote telecom sites. The resulting calculations from these refined models showed where the application of the ZBM design would likely save the user more fuel with an indication that different characteristics of energy storage allow specific designs to save fuel more effectively, validation of real sites, and the potential to study multi-generator micogrids.

Discussion

Benjamin Schenkman

Developing Metrics for Electric Energy Storage through an Application Model

The modern grid can utilize electrical energy storage (ES) devices in several different applications that offer ancillary services like frequency regulation, load following, reactive power and voltage control, and energy imbalance. Because of duty cycles associated with storage systems, the ideal attribute of a deployed grid-scale storage demonstration project incorporates proper controls that optimize performance regardless of charge or discharge state. Some of the control signals capable of providing services to electric utilities are stochastic in nature. In order to quantify the performance of such services, statistical properties associated with the ES device can be used.

In statistics, the autoregressive (AR) model is a very good representation of time-variant, random processes. Our team used the AR model to extract the required properties of an ES device that is part of a system. Once extracted, the quantitative results can be reproduced and used as test signals in a laboratory setting. The AR model parameters selected were as follows:

Model Equation
$z(kT) = a_1z((k\text{-}1)T)+a_2z((k\text{-}2)T)+a_3z((k\text{-}3)T)+a_4k((k\text{-}4)T+v(kT)$

Prediction Based on Model
$\check{z}(kT) = a_1z((k\text{-}1)T)+a_2z((k\text{-}2)T)+a_3z((k\text{-}3)T)+a_4k((k\text{-}4)T+v(kT)$

Prediction Error
$e(kT) = z(kT) - \check{z}(kT)$

Performance Metric
$J = ||e||^2/||z||^2$

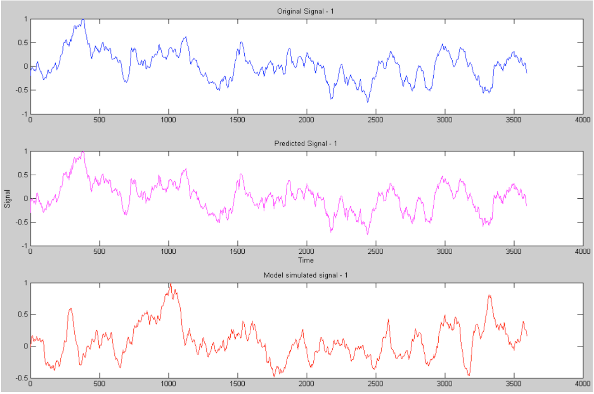
v(kT) is noise input taken as zero mean Gaussian white noise with variance given by the AR modeling calculations

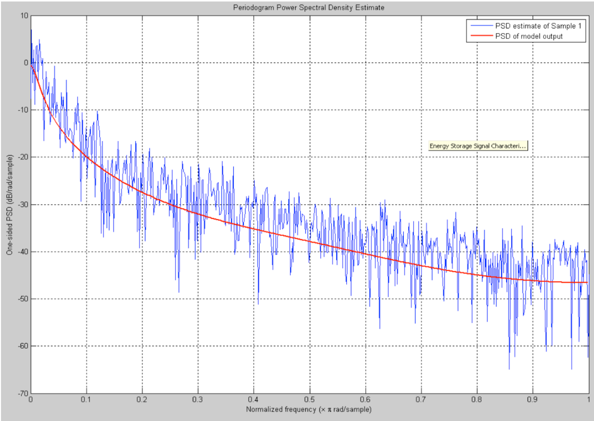
In our work, this model was used for parameter estimation. For AR, predictive performance of the model can be assessed after the estimation has been validated.

The PJM interconnect is a regional transmission organization (RTO); it is the world's largest competitive wholesale electricity market that serves all or most of Delaware, District of Columbia, Maryland, New Jersey, Ohio, Pennsylvania, Virginia and West Virginia, parts of Indiana, Illinois, Kentucky, Michigan, North Carolina and Tennessee. PJM makes real-time electricity market data like current demand and peak demand available via internet. This study utilized PJM demand data from April 2011 to March 2012.

The four graphical representations of model validation depict recorded utility signals, an AR model of the signal, a random signal with utility signal characteristics, and the power density estimate of the original signal versus the random simulated signal.

Model Validation

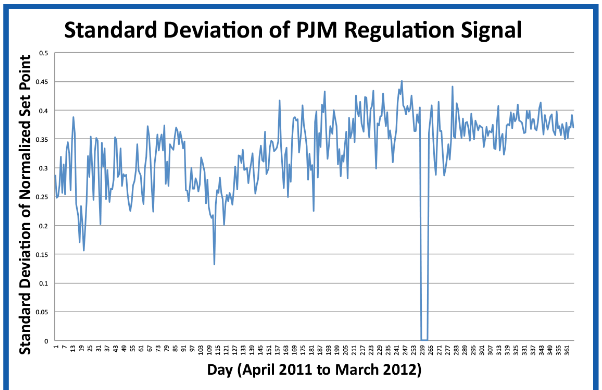


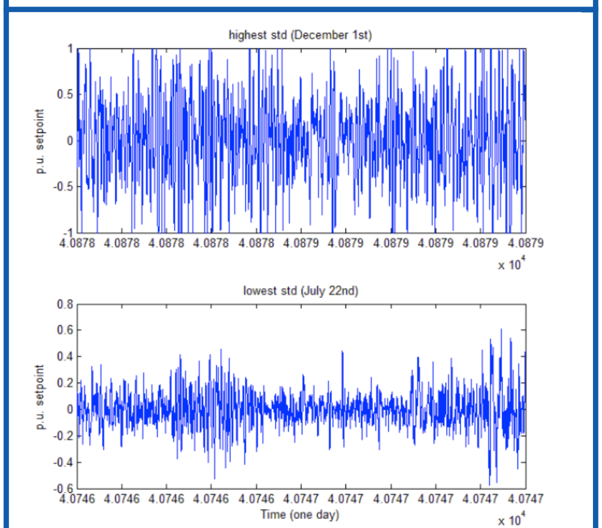


With a set of predicted values and a corresponding set of actual performance values for the ES device for various time periods, we used a common evaluation technique, the mean square prediction error. The mean square prediction error helps with smoothing or curve-fitting.

Project Team Members: Benjamin Schenkman, David Rose, Summer Ferreira, and Pramod Khargonekar

The previous graphs were based upon a set of datapoints for one month of the PJM regulation signal. Since the load varies from the summer months to the winter months, the standard deviation of the PJM regulation signal was created for a year time period. As shown in the following graphs, the standard deviation varies quite a bit between the summer and winter months.



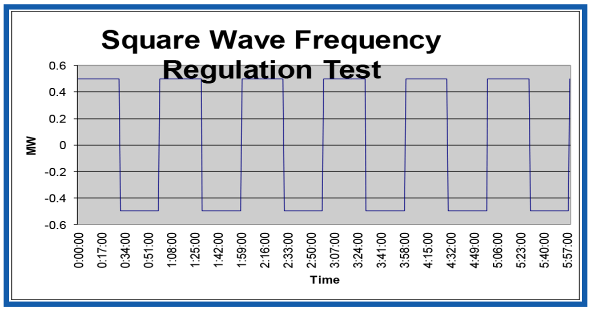


	Min	Mean	Max	Std	Min Delta	Mean Delta	Max Delta	Std Delta
Min	-1.000	-0.015	0.607	0.132	-0.800	0.000	0.056	0.012
Mean	-0.994	0.000	0.993	0.333	-0.166	0.000	0.175	0.023
Max	-0.578	0.007	1.000	0.451	-0.055	0.000	0.800	0.030
Std	0.034	0.002	0.038	0.057	0.081	0.000	0.094	0.003

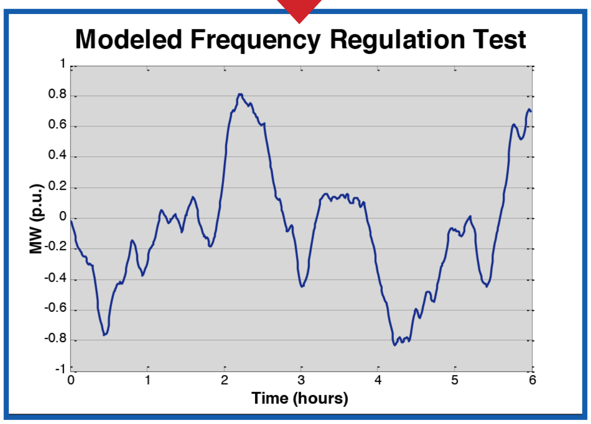
The highest standard deviation of PJM's regulation signal occurred December 2011; the lowest standard deviation of the same signal occurred July of the same year.

Effect on Testing Standards

The signal that is sent to an energy storage system currently for testing is called the square wave approximation. Amplitude of the square wave is the Depth of Discharge (DoD) for an energy storage system and the duty cycle is the duration of the signal. Square wave approximation suffers in accuracy due to the fact that when the energy storage is applied in the field, the amplitude and duration of the signal for the application varies throughout the day. It is not conclusive that the variation in the DoD and duration has an impact on the life cycle of the energy storage system. Sandia has an ongoing effort to determine just how much impact the variation of the DoD and duration has on the life cycle of an energy storage system.



We are progressing the state of the art in energy storage testing by determining the benefits (if any) of using more realistic duty cycles



Though this research had a sound approach using AR modeling, it was not sufficient to provide conclusive evidence for ES controls in a grid-tied system. Work continues in the energy storage demonstration program ESDP to validate the model with real data that may require a suite of statistical techniques to accurately represent the regulation signal for variations in winter and summer and daytime and nighttime conditions for stationary electrical energy storage systems (ESS) installations. Furthermore, the storage metrics experiment described here serves as a good basis for the duty cycle used in the August 2013 Department of Energy's performance protocol for frequency regulation.

Discussion

Dr. David Schöenwald

Electricity Grid Growth, Reliability & Resilience Challenges: System Stability and Energy Storage

In a power system, small disturbances called oscillations occur constantly due to load changes. The system must be able to continuously adjust to these small oscillations and successfully operate to meet load demand. The continuous adjustment is called damping; it has the effect of reducing the amplitude of the anticipated oscillations. An electric grid operator can expect small oscillations in each generator which may seem inconsequential. They do, however, become significant if the fluctuations add up to become a tie-line oscillation. In this paper, the term tie-line is used to describe a service that may involve dedicated circuits, switching arrangements, or predefined transmission paths. Higher tie-line loading can increase the tendency to oscillate as well as the significance of the oscillation.

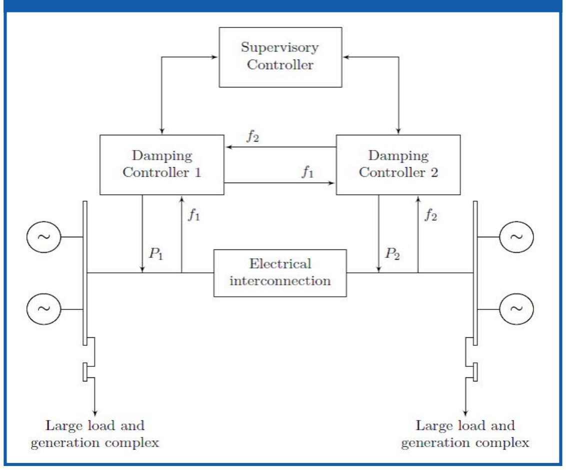
Over time, as the original US grid grew larger and westward, it required more generation and more transmission over extended areas in the west along with interconnections. Just as a system must be able to withstand many small disturbances, it must also survive oscillations that are severe like the loss of a large generator or short circuits in the transmission line. The initial solution was to improve system function by increasing transmission lines.

As smaller power systems grew in size and capability, there was greater commercial pressure for grid operators to use additional transmission lines for economical energy transfer even if the additional line was built as an aid in maintaining system reliability. Due to the nature of the power system, oscillations can be reduced but never eliminated. In fact, there are at least three problems experienced by electric power utilities with respect to frequency oscillations: local plant oscillations, control (mode) oscillations, and inter-area oscillations. Jason Neely, et.al, have determined a novel approach of utilizing energy storage to address reliability, resilience, and stability by modeling Ultra-Capacitor technology on selected buses in the Western Electric Coordinating Council (WECC).

Damping of Inter-Area Oscillations Using Energy Storage

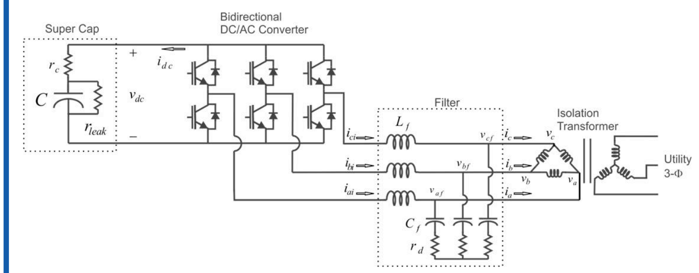
Low frequency inter-area oscillations have been identified as a significant problem in utility systems due to the potential for system damage and the resulting restrictions on power transmission over select lines. Previous research has identified real power injection by energy storage based damping control nodes as a promising approach to mitigate inter-area oscillations. In this research, a candidate energy storage system based on UltraCapacitor technology is evaluated for damping control applications in the Western Electric Coordinating Council (WECC), and an analytical method for ensuring proper stability margins is also presented for inclusion in a future supervisory control algorithm. Dynamic simulations of the WECC were performed to validate the expected system performance. Finally, the Nyquist stability criteria was employed to derive safe operating regions in the gain, time delay space for a simple two-area system to provide guaranteed margins of stability.

Fig.1 Oscillation damping using real power modulation



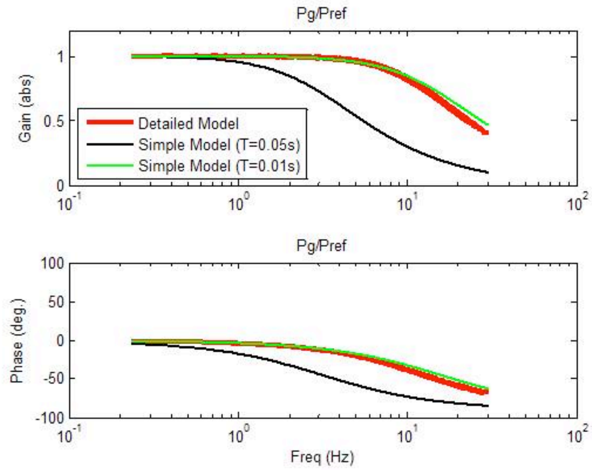
Two *damping controllers* located in different areas, a communication link, and a *supervisory controller* that oversees the control. The damping controllers operate by sourcing or syncing power in each area proportional to the frequency difference between areas.

J.C. Neely, R.H. Byrne, R.T. Elliott, C.A. Silva Monroy, D.J. Trudnowski, M.K. Donnelly

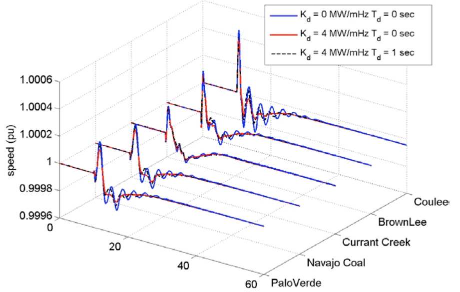


Candidate Energy Storage System and Simplified Inverter Model

A practical candidate system was developed based on Ultra-capacitor energy storage for which a detailed full state model was generated to represent the storage system dynamics including: filter inductor currents, filter capacitor voltages, transformer reactances, ultra-capacitor voltage and the control integrator.

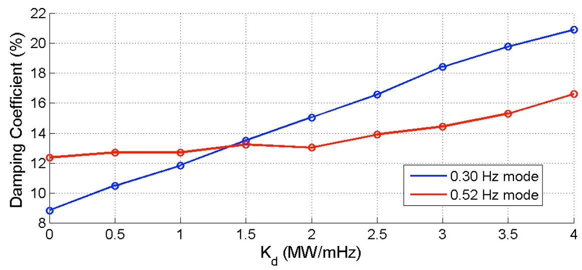


The system reference power P_{ref} was implemented using a chirp signal; the power output to the grid was then evaluated for gain and phase. For comparison, the same was done for a simple first order system.



Simulation

An UltraCapacitor-based oscillation damping system was modeled in PSLF using a simple first order approximation and scaled up to represent many parallel connected units. In simulation, the system was placed at Palo Verde (bus 15021) and Grand Coulee Dam (bus 41356) within the existing 2017 Heavy summer WECC base case. A transient inter-area oscillation was excited by simulating a fault on a 500kV power line in British Columbia (CBK500) at t=10 seconds.



Prony Results

As K_d varied from 0 to 4 MW/mHz (with Td=0), the difference in generator speeds at Palo Verde (PALOVRD2 A14 - bus 14932) and Coulee (COULEE22 A40- bus 40296) were computed at each gain value and the ringdown response was evaluated using Prony analysis to extract mode frequency and damping information.

Conclusions

Development of a supervisory control scheme based on this analysis is the subject of ongoing work. Nonetheless, the results presented herein reinforce the feasibility and potential value of energy storage based damping control.

Discussion

Jacquelynne Hernández

A Convergence of Energy Policy, Economics, Markets, and Engineering

There was applause at the close of the Electrical Energy Storage Applications and Technologies Conference in 2011, after Dr. Imre Gyuk announced that the Federal Energy Regulatory Commission (FERC) had issued a Final Rule for Order 755, Frequency Regulation Compensation in Organized Wholesale Power Markets. The Order can be described as "pay-for-performance." It requires compensation by grid operators in organized markets for fast-ramping frequency resources like battery storage facilities, flywheels, and other similar storage technologies.

Now, the 2013 EESAT Conference begins with the Final Rule for Order No. 784—in place since July 18, 2013. The name of this Order is "Third-Party Provision of Ancillary Services: Accounting and Financial Reporting for New Electric Storage Technologies." The latest ruling sets up a natural competition of fast batteries, flow batteries, and flywheels against slower conventional coal-fired and gas-fired plants in the ancillary services market. The Order further expands Order 755 such that speed and accuracy are part of a utility's consideration when purchasing regulation services for transmission. The new Order may also help a utility to realize rate recovery for storage equipment and facilities.

Eric Wesoff of Greentech Media suggested, "Even if the price of grid-scale energy storage fell to zero dollars per megawatt-hours, then regulators would still not know how to properly position energy storage to take advantage of market opportunties." If you regard the image illustration below, the regulatory confusion is no longer a joke, but a reality that is uncertain.

Electrical Energy Storage Icon developed by Mona Aragon of Sandia National Laboratories to illustrate that storage can be in the asset class for generation, distribution, and load.

Energy storage does not fit perfectly into the regulatory apparatus for developing market guidelines in the traditional electricity delivery system that includes the big three: generation, transmission, and distribution. It also does not have a model in the utility rate recovery structure, either. So how does one make money, a market, or sense of electricity storage? Interestingly enough, software and controls engineers are working ahead to develop optimization schemes that will be ready when the market designers and regulators converge.

Karina Muñoz
Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Project Optimization

Technology Management Optimization (TMO) was designed to help optimally manage high-value, long-lived equipment over the lifetime of a system. Users define choices that affect the performance parameters of the system, and then TMO performs an optimization of the system, using input from the reliability model and analyzes how these user-defined choices affect the relevant performance parameters of the system.

The Performance/Reliability Model (PRM) was developed to increase understanding of the impact that power loss has on critical missions at military bases. PRM allows for comparisons between different energy systems configurations to evaluate key tradeoffs, costs and performance indicators. This model takes inputs such as system configuration or energy assets and calculates applicable metrics.

TMO uses the PRM which accepts inputs and returns the metrics of interest. TMO iteratively produces candidate solutions and executes the simulation to determine how well they perform against the performance metrics. With each iteration, the model attempts to take advantage of newly learned information to formulate better candidate solutions. This process continues until it can no longer make any progress, at which point it stops and presents the current candidate solution as the final solution.

James Ellison

A production cost model is a useful tool for understanding how much a storage resource might save power production costs over time. This model takes the load and renewable generation as inputs, contains detailed information about the generation units (heat rate curves, ramp rates, etc.), and solves the unit commitment and dispatch problem – aiming to find the least cost.

An advantage of this approach is that you can analyze potential future changes in the grid, and verify how these would change the value of storage. Another advantage is that this model does not require historical prices or markets, and therefore could be used in areas served by regulated utilities.

Dr. Raymond H. Byrne

As part of the effort to evaluate the performance of the ARRA (American Reinvestment and Recovery Act) energy storage demonstration projects, Sandia developed optimization algorithms for estimating the maximum potential revenue from an energy storage system participating in arbitrage and the frequency regulation market. The inputs to the algorithm are the characteristics of the energy storage system: conversion efficiency, storage efficiency, maximum energy, maximum charge rate, and maximum discharge rate. Required market information includes energy and regulation prices for the period of interest. The algorithm calculates the maximum possible revenue for the system. If cost information is available, the algorithm can calculate the maximum present value of the system. Since the algorithm relies on perfect information, it provides a maximum upper bound to baseline other algorithms.

Dr.César Augusto Silva-Monroy

SNL, in combination with other institutions, is developing tools for improved power system operations based on advanced stochastic optimization algorithms. Power system operations refers to daily operations, while planning refers to longer term investment decisions. The complexity of both operations and planning is increased when renewable energy and energy storage resources are considered.

Availability of renewable energy resources is very difficult to forecast. The same can be said for energy storage, due to its energy limitations for some technologies. We make use of probabilistic forecasts that take into account the uncertainty in the forecast of renewable resources. That is, we employ probabilities associated with a range of forecast scenarios to optimize for minimum expected costs (stochastic) instead of assuming a single forecast made about a resource is correct and optimizing for that single forecast scenario (deterministic). This method results in decisions that, over time, produce operational costs when compared to decisions made with deterministic methods.

Energy Storage Demos

There are four Energy Storage Demonstration Project categories in this journal: CESA, California, DoD, and Storage Optimization. CESA is the acronym for Clean Energy States Alliance. It is a non-profit organization that works with states, federal agencies, and the energy industry stakeholders to promote renewable energy, energy efficiency, and clean energy technologies. The objective of CESA's Energy Storage Technology Advancement Partnership (ESTAP) is to "accelerate the pace of deployment of energy storage technologies in the United States through the creation of technical assistance and co-funding partnerships between states and the U.S. Department of Energy."

California has rapidly approaching deadlines associated with their Renewable Energy Portfolio Standards (RPS). An RPS is a regulatory requirement for the increased production of energy from renewable resources like wind and solar. The electric supply company is mandated to produce a specific amount of their electricity from a renewable energy resource. In September 2010, the California State Assembly passed AB 2514—landmark legislation that requires investor-owned utilities to establish procurement targets for cost-effective energy storage systems to be achieved by December 31, 2015, and an additional target to be achieved by December 31, 2020, such that 33% of the energy generated in California will be from renewable energy resources.

The Department of Defense seeks to explore the use of energy storage for the microgrid. Mesa del Sol and Duke Energy are participants in the Energy Storage Demonstration program to seek optimization of voltage and frequency regulation schemes to meet the needs of critical mission facilities for the end user. The category listed as Miscellaneous contains a feasibility study, a road map exercise, a user's guide for evaluating energy storage markets, and a conceptual design.

CESA

Alaska – Kodiak & Venetie
Connecticut – DEEP
Pennsylvania – Aquion
Massachuetts – InnnovateMass
North Carolina – Duke Energy
(See Storage Optimization)
Texas Tech – Wind Resources Support

California

University of California at San Diego
SunPower/TOTAL

DoD Microgrid

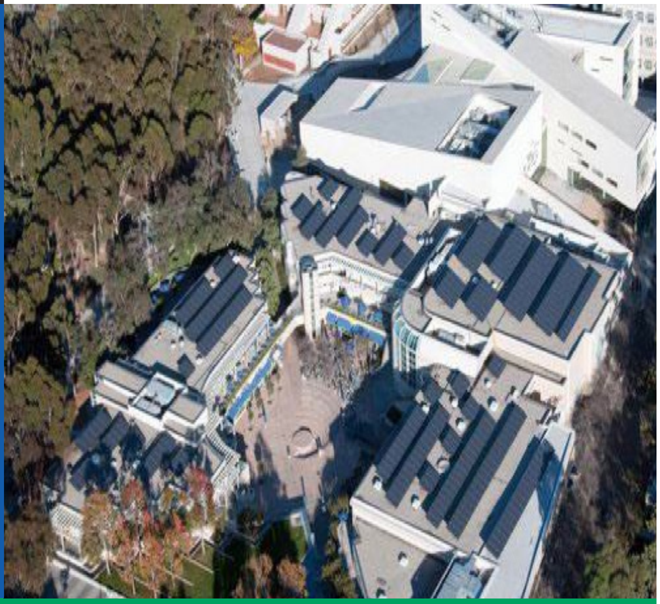
BCIL
Pearl Harbor

Storage Optimization

Mesa del Sol – PNM/ Prosperity
Duke Energy – Rankin Engine

Miscellaneous (To be featured in the a future summary journal)

Reading Municipal Light Department – Feasibility Study
NAATBatt – Distributed Energy Resources Roadmap
KEMI, E&I Consulting – Energy Storage Market Potential Assessment Guide
Helix Power – Conceptual Design (Flywheels)



University of California at San Diego

DOE/SNL Active Demonstration Projects - FY2013 Overview

Partner	ES Vendor	System	Size	Location	Application
PM-FSS	Milspray, Princeton, Ktech, GS Yuasa, Earl	Milspray 15kW 2hr LA PP – 100kW 40min Li-ion; Ktech – 10kW 4hr redflow zinc GS – 70KVA 1hr VRLA; Earl – 100kW 40min Li-ion		BCIL	Military Forward Operating Base Microgrid generator fuel reduction
UCSD	TBD	3-5 systems will be selected	3.6MW 2 hours	UCSD Campus	Campus Microgrid (with PV) support
SunPower/DNV-KEMA/UCSD	ZBB	ZnBr	125kW 4hr	UCSD	PV W/ES performance and economic value
Kodiak Electric/Alaska Energy Auth/Alaska Energy	Xtreme power	XP lead acid	3MW 15 min	Kodiak, AK	9 MW wind support
ERDC-CERL/SPIDERS	ZBB	ZnBr	125kW 4hr	Pearl Harbor Hickam	Microgrid support
DUKE	Fiamm	NaNiCL Zebra	400kW 40min	Rankin site	PV Smoothing
Texas Tech/SNL	Xtreme Power	Samsung Li-ion	1MW 1 MWh	Reese Wind Site (SNL Wind Facility)	Wind support
Aquion/Pennsylvania Dept. of Energy	Aquion	Aqueous Sodium	50-100kW 1hr	Pittsburgh Facility	Grid connection
Mesa del Sol/NEDO/PNM	East Penn	Lead Acid	500kW -40 min: 250 kW – 2hr	Mesa del Sol	PV smoothing and energy shift
Connecticut Dept. of Energy	TBD	TBD	TBD	Connecticut	Energy storage on emergency microgrid
Massachusetts Dept. of Energy	TBD	TBD	TBD	Massachusetts	Energy storage on emergency microgrid

Energy Storage Demos

ALASKA COLLABORATION–KODIAK ELECTRIC AND VENETIE

Project Description:

Kodiak Electric has added 4.5MW of wind power to an existing 4.5MW of wind, giving them a total of 9MW of wind. In order to manage this additional 4.5MW of wind, Kodiak installed a 3MW 15 minute Xtreme battery system. In this project DOE/SNL will work with Kodiak Electric Association (KEA), Alaska Center for Energy and Power (ACEP), Alaska Industrial Development and Export Authority (AIDEA), to gather performance data, and study the impacts of wind and energy storage in order to understand the benefits and how ES and renewables might apply and benefit other Alaska electrical grids and projects. DOE/SNL will also look at optimizing schemes to further the economics of the project.

Key Project Events/Milestones:

- 9.0MW wind in operation 12/12.
- 3MW Xtreme Battery in operation Q4/FY13.
- Analyze initial data.

Three of the six 1.5MW wind turbines on Pillar Mountain, Alaska

CLEAN ENERGY STATE ALLIANCE–ESTP DEMONSTRATIONS: CONNECTICUT DEEP, INNOVATE MASS, OTHERS

Project Description:

As part of DOE's mission to proliferate energy storage adaption, a contract was put in place with CESA to develop and manage a program that would educate the states' energy offices in the benefits of energy storage and help in developing state led ES demonstration projects.

Key Project Events/Milestones:

- FY13 Plan in Place 2/2013.
- Develop two collaborations with states to support their efforts to incorporate energy storage into their energy strategies:
  - **Connecticut** – Provide technical review of proposals that contain energy storage systems in Connecticut's RFP for grid resiliency. Provide services to analyze project installation and data. Support placement of contract for at least one project that includes ES.
  - **Massachusetts** – Provide technical review of proposals submitted for clean energy projects in the state of Massachusetts. Provide services to analyze project installation and data. Support placement of contract for at least one project that includes ES.

AQUION ENERGY

Project Description:

Aquion is in the process of taking their prototype that was designed and built under the ARRA program to the next step of building a 50-100kW/1hr aqueous battery. This will be building block to their eventual full scale 1M/1hr ES demonstration at their new Westmoreland, Pa. manufacturing facility. As part of this effort DEO/SNL will support the building and testing of the 50-100kW unit by issuing a contract to fund specific tasks needed to engineer and build the system.

Key Project Events/Milestones:

- Scope of work and deliverables to fund design improvements of battery housing completed by end of February, 2013. Contract to further develop battery housing in place by end of April, 2013.
- Conduct testing of Aquion cells
- Initial test report due by end of Q4/FY13.

TEXAS TECH REESE WIND SITE

Project Description:

Sandia, as part of their ongoing R&D efforts with Texas Tech University, is installing approximately 900kW of wind power at the Reese test site located on the campus of TTU. As part of this program, DOE, under the ARRA award, has provided ~$1.7M to TTU to install an Energy storage system. The system will be tied to the SNL site, additional substations and wind turbines. DOE/SNL will utilize this test facility to conduct R&D in the operation and control of ES in Wind power applications.

Key Project Events/Milestones:

- Installation of three ea. 300kW wind turbine is in process. Est. completion date 3/2013.
- RFP issued and awarded to Xtreme Power who will provide a 1MW/1hour Li-ion system. System expected to deliver Q3 FY13.
- Data acquisition system design to be completed and installed by Q3 FY13.

UNIVERSITY OF CALIFORNIA SAN DIEGO COLLABORATION

Project Description:

UCSD was awarded a $4.3M grant under the CPUC's Self Generation Incentive Program (SGIP) to purchase and install (grant only for hardware) >4MW/5MWh of Energy Storage. The project is looking to install three systems – 2.5MW/2 hr, 500kW/2hr, and a ~650KW/2hr. This system will be installed on the University's microgrid. DOE/Sandia is collaborating with the University in development of the project and conducting research of the Energy Storage systems. DOE/SNL will provide technical consulting and support in the following areas:

- Development of project plans and RFPs.
- Development of Data acquisition system design, installation plans and data collection.
- Support startup and commissioning.
- Monitor and analyze data.
- Conduct research and development on how to operate and optimize Energy storage in microgrids, renewables, and other applications including military.
- Develop and issue report of findings for general publication.

Key Project Events/Milestones:

- RFP Issued Q3 FY13.
- Issue RFP for 2.5 MW/2 hour energy storage system(s) by Q4/FY13, and award contract(s) to purchase and install systems by end of Q1/FY14.

SUNPOWER ES DEMONSTRATION WITH PV

Project Description:

SunPower Corp under a grant from the California Public Utility Commission (CPUC) will demonstrate Electrical Energy Storage (EES) with PV, and the benefits that EES might provide. The Project will install two EES systems, ICE Energy at KOHL's department store (Redding, Ca.) and a ZBB- 125kW/4 hr flow battery at UCSD. The systems will be installed on existing PV systems. DOE/Sandia will provide technical consulting services and assist KEMA in the evaluation of the ZBB energy storage system by supporting the following activities:

- Development of project plans.
- Development of data acquisition system, placement of system and data collection.
- Support startup and commissioning.
- Support KEMA in developing final report writing by providing the technical analysis portion to their overall report covering both economic and technical performance.

Key Project Events/Milestones:

- Finalize SunPower-UCSD lease agreement, designs and installation plans: 3/1/13.
- Prepare data monitoring, testing and system evaluation plan: Q3/FY13.
- Manufacture, ship, install and commission ZBB system; begin data collection: Q3/FY13.
- Conduct 6-month system assessment, test and results validation; deliver report: Q1/FY14.
- Conduct final, end-of-project,12-month system as sessment and issue report by end of Q1/FY15.

SunPower Electrical Energy Storage, California

Energy Storage Demos

BASE CAMP INTEGRATION LAB (BCIL) ENERGY STORAGE DEMONSTRATION

Project Description:

DOE-OE/Sandia is collaborating with Army Program Manger Force Sustainment Systems (PM FSS), to develop demonstrations at an experimental Forward Operating Base (FOB) to analyze energy storage's capability to increase the reliability of the electrical power microgrid at a FOB while decreasing the fuel consumption of the system. Five ES vendors will conduct demonstrations at Sandia National Labs, then (if meritorious), again at BCIL's test forward operating base located at FT. Devens, MA. Note: Presently we are in discussions with MIT-LL to conduct testing on the FOB microgrid.

The five vendors include:

Milspray–15kW/79kWh; Deeka VRLA; to SNL 1/13
Princeton Power–100kW/60kWh; Li-ion; to SNL 3/13
Earl Energy–60kW/40kWh; Li-ion; to SNL TBD
Raytheon/Ktech–30kW/120kWh; Red Flow Zinc Bromine; to SNL 3/13
GS Yuasa–70kVA 100kWh VRLA; to SNL 6/13

Key Project Events/Milestones:

- RFI issues and vendors selected Q1 FY13.
- First system due to SNL DETL for testing Q2 FY13.
- One or two systems selected and sent to BCIL Q3 FY13.
- Complete testing of five ES Systems at DETL Q4/FY13 to determine system reliability and operability. Issue report of findings by end of Q1/FY14 and provide to BCIL personnel. Issue individual reports to vendors discussing system performance.

PEARL HARBOR-HICKAM (SPIDERS)

Project Description:

The first SPIDERS (Smart Power Infrastructure Demonstration for Energy Reliability and Security) microgrid was implemented at Joint Base Pearl Harbor-Hickam in Honolulu; it takes advantage of several existing generation assets, including a 146kW photovoltaic solar power system, and up to 50 kW of wind power. SPIDERS is funded and managed through the DoD's JCTD as part of the DOE/DoD Memorandum of Understanding (MOU). The US Air Force provided funding to the project to purchase and install a 125kW/4hr ZBB flow battery.

This project will support Concurrent Technologies Corporation (CTC) in conducting an analysis of the system and issuing a report of findings concerning the operation of the ES system in a microgrid application. Work will be in support of the DOE/DoD MOU.

Key Project Events/Milestones:

- ZBB system operational–12/2012.
- Review Data Acquisition system and start collecting Data 3/2013.
- Provide technical and project management support to define, develop, and implement solution to solve system's control problem. Implement fix and commission system by end of Q1/FY14.

MESA DEL SOL (MDS)

Project Description:

Sandia National Laboratories has created a PV power smoothing algorithm incorporating multiple distributed resources (e.g., batteries, fuel cells, natural gas engine-generator). Simulations to smooth the PV output have shown significant reduction in battery state of charge range and power conditional system size when using a traditional power generator (gas engine-generator) in conjunction with a battery. To verify these benefits, the PV power at the Public Service Company of New Mexico (PNM) Prosperity site will be smoothed with the PNM Prosperity battery in conjunction with the MDS gas engine-generator and fuel cell at the Aperture Center. Two tests have been proposed to compare coordinated and distributed control systems to battery operation alone: (1) creating a step change in the PV output by disconnecting a portion of the PV system and (2) artificially replaying the PV output signal to the gas engine-generator and battery system in software.

Key Project Events/Milestones:

- Test plan was updated on 7/2/13 and sent to PNM and NEDO/Tokyo Gas/Shimizu for review.
- July 15th–Toshiba will send PI tags and port information to PNM.
- July 15th–Sandia will create VB code for replaying PV, GE, and FC power profiles.
- July 15th–Tokyo Gas will select a high variability day for replaying PV, GE, and FC profiles and provide data to PNM and Sandia.
- Late July–Test Toshiba PI-PNM PI communications.
- Aug 5-7–Test A – Real-time control with PV disconnect.
- Aug 8-9–Tokyo Gas picks a previous day to replay. BEMS runs with MdS replay with and without communication.
- Aug 10-17–Run system with real-time coordination on a variable day. Replay day without communication.

DUKE ENERGY RANKIN SITE EVALUATION

Project Description:

Duke Energy has installed a 402 kW/282 kWh, NaNiCl energy storage system to mitigate PV-induced power swings. Duke Energy has asked DOE/Sandia to collaborate with them to help further utilize their system to optimize energy storage in utility grid applications. In this project, we will look to develop control algorithms that will increase the utilization of the ESS, thereby creating additional value. In addition to PV smoothing, ESS functions that will be investigated include active VAR/Power Factor (PF) management and combined Watt/VAR voltage control. The project will also investigate the ability of the ESS to mitigate the impact of PV-induced power swings on substation assets such as load tap changers, transformers, and relays.

Key Project Events/Milestones:

- System installed at the Rankin Substation, Mount Holly, NC–12/2011.
- Operational–3/2012.
- Sandia site visit with Duke staff – 6/2013.
- System evaluation and algorithm development Q4 FY13–Q1 FY14.

Mesa Del Sol

Biographical Notes

Biographical Notes for EESDP Journal Article Contributors:

Dr. Imre Gyuk
Dr. Imre Gyuk has a B.S. from Fordham University, and he completed his graduate work at Brown University where he was a research assistant to Nobel Laureate, Leon Cooper. After obtaining his Ph.D. in Theoretical Physics from Purdue University, he became a research associate. Dr. Gyuk has taught Physics, Civil Engineering, and Architecture at the University of Wisconsin and Kuwait University.

Now, Dr. Gyuk directs the energy storage research program at the U.S. Department of Energy, which funds work on a wide variety of technologies such as advanced batteries, flywheels, super-capacitors, and compressed air energy storage.

Dr. Sean Hearne
Dr. Sean Hearne received his B.S. in Aviation Technology from Embry-Riddle Aero University. He went on to acquire a Ph.D. on Solid State Physics from Arizona State University.

Dr. Hearne is now serving as a manager for the Electrical Energy Storage group at Sandia National Laboratories where he continues to develop and hone his skills and expertise in Materials Science, Nanotechnology, and Semiconductors.

Mr. Daniel Borneo
Mr. Borneo is an Electrical Engineer and Principal Member of Staff at Sandia National Laboratories. He holds both a B.S.E.E. and M.S.E.E. from the University of New Mexico. In 2012, he became a scholar-in-residence at the University Of California San Diego (UCSD) where he now serves as a consultant. At SNL, he serves as the principal investigator and project leader for the Department of Energy/Office of Electricity (DOE/OE) Electrical Energy Storage Systems (ESS) Demonstration Program. His primary focus is collaborating with representatives of the energy storage industry, academia, and state energy groups to facilitate moving innovative electrical energy storage technologies and systems to commercialized products and services.

David M. Rose: B.S.E.E. and M.S.E.E., Montana Tech of the University of Montana; Areas of Expertise: Energy Storage Testing, Experimental Design, Data Collection and Analysis, Energy Systems (Conventional and Renewable), Power Engineering Theory, Modeling, and Application

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Jason C. Neely: B.S.E.E. and M.S.E.E., University of Missouri-Rolla; Ph.D. Purdue University, Control of Power Electronic Systems; Areas of Expertise: Control Theory; Signal Processing; Robotics; Embedded Systems; Machines and Drives; Power Electronics

David Schoenwald: B.S.E.E., University of Iowa; M.S.E.E., University of Illinois at Urbana-Champaign; Ph.D. Electrical Engineering, The Ohio State University; Areas of expertise: Control Theory; Robotics; Electrical Energy Storage

Karina Munoz-Ramos: B.S. Electrical Engineering and M.S. Electrical Engineering, New Mexico Institute of Mining & Technology; Areas of Expertise: Power System Modeling & Simulation, Energy Surety Microgrid Design and Systems of Systems Modeling, Simulation & Analysis

Benjamin Schenkman: B.S.E.E. and M.S.E.E., New Mexico State University; Areas of expertise: Power System Analysis, Microgrid Design and Control, Energy Storage Optimization and Control

James Ellison: B.A. Physics and B.A. Political Science, Clemson University; M.S. Technology and Policy, and M.S. Mechanical Engineering, Massachusetts Institute of Technology; Areas of Expertise: Grid Modeling for Renewables Integration and Storage Valuation, Power Plant and Distribution Company Operations, Project Development and Financial Aanalysis

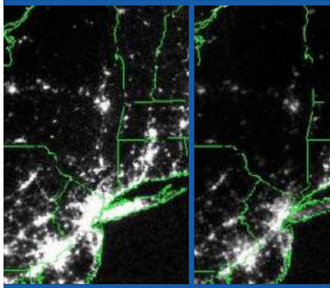
Raymond Byrne: B.S.E.E., University of Virginia; M.S.E.E., University of Colorado; M.S. Quantitative Finance, University of Chicago; Ph.D. University of New Mexico; Research Area: Control Theory

Cesar Augusto Silva Monroy: Electrical Engineering, Universidad Industrial de Santander; M.S.E.E., University of Washington; Ph.D. University of Washington, Power System Operation with Energy Storage under High Penetration of Renewable Energy

Jacquelynne Hernández: AB History/Physics, Vassar College; B.S.E.E.T. – DeVry Institute, M.S.E.E. – New Mexico State University; Areas of Expertise: Asynchronous Machine Modeling & Validation, Electricity Utility Management, and Energy Policy (O&G Pipelines, Energy Cyber Standards, RTO/ISO Market Compliance)

Afterword

NYC Blackout 2003 and NYC Survival of Hurricane Sandy where ESS used.



The practice and direction of the Electrical Energy Storage Demonstration Program (EESDP) are consistent with the mission of the DOE. The approach to problems and challenges is systematic. So what is next for the EESDP? Perhaps it makes sense to briefly look back to better predict the future and the best path forward for the emerging and enabling technologies associated with energy storage.

Dr. Imre Gyuk, at the DOE Office of Energy Delivery and Reliability continues at the forefront in leadership to grow the electrical energy storage program toward the creation of an intelligent, purposed, unparalleled market design that benefits our national energy security goals.

Dr. Sean Hearne, the Manager of Energy Storage and Technology Systems at Sandia National Laboratories, is responsible for performing risk assessments that include the smart grid and microgrids with respect to the elements of energy surety: safety, security, reliability, cost effectiveness, recoverability, and sustainability.

Mr. Daniel Borneo, the Electrical Energy Storage Demonstration Program Project Manager, works from a triad construct that includes research and development, technology applications, and deployment of complete storage systems in an effort to mix science and business to ensure the commercial viability of products, modules, and systems to provide meaningful services for the end user in the electricity delivery chain.

Energy Storage Leadership at Sandia National Laboratories Looking Forward:

Karen Waldrip of Advanced Power Technologies leads a multidisciplinary team that continues to add to the transformational architecture in material science research and development which encourages collaborative work across national laboratories that helps widen exposure in addressing challenges and finding solutions for energy storage technology gaps for the next generation of power electronics; and

Stan Atcitty, who is responsible for applications that enhance power electronics, works with colleagues and mentors students in projects that tend toward the technological edge for state-of-the art scientific discovery for fabricated products in the power conversion world that support grid resilience and set industry standards.

The next generation of leaders includes test engineers like *David Rose* and *Summer Ferreira*, power engineers like *Karina Munoz*, *Benjamin Schenkman*, and *Jay Johnson*, quality engineers like *James Ellison* and *Cesar Augusto Silva Monroy*, software and controls engineers like *David Schoenwald*, *Jason Neely* and *Ray Byrne*, whose work in energy storage demonstration projects result in optimizing function, performance, operations, and stability of the grid.

Clearly, the record of successes in the Electrical Energy Storage Program is based on the interfacing of all the elements that characterize how problems and challenges are met and resolved in the variety of energy storage demonstration projects in this journal. And, undoubtedly, the next logical step in energy storage exploration will require carefully crafted regulations, guidelines and collaborative efforts for the installation and operation of energy storage devices, equipment, and facilities for the next generation electrical grid and its end users.

The Upcoming 2014 Energy Storage Demonstration Projects include:

- *Reading Municipal Light Department – Feasibility Study: Battery Storage in a Historic Power Plant & a Substation*
- *NAATBatt – Distributed Energy Resources Roadmap: Applications & Benefits to the Electric Utility Industry*
- *DNV KEMA and E&I Consulting – Assessment Guide: Energy Storage Market Potential Update*
- *Helix Power – Conceptual Design (Flywheels): Exceptional Capabilities for Power System Performance*
- *SNL Small & Large Battery Testing: User Facility at Sandia Labs*